ECL 203

ENGINEERING CASE LIBRARY

CUSTOM CYCLE

Mike Bailey builds extended front forks for customized motorcycles. He has confidence that his product looks and rides better than others on the market, but he wanted some engineering evidence to show that it was safe.

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Customized motorcycles, or choppers, are becoming popular throughout the country, and are especially prevalent in California. As the word "custom" implies, each of these choppers is different, and reflects the individual tastes of the owner. The infinite variety of possible modifications makes the classification of their benefits very difficult. Some modifications would appear to improve handling or comfort for sustained high speed travel. Others, however, definitely give the chopper a harder or a less stable ride. The only common quality for each modification appears to be that, in the eye of the owner, the appearance of the chopper is enhanced. For this effect, he is willing to sacrifice handling, stability or sometimes even comfort.

A popular misconception about choppers should be dispelled here. As with anything which is customized, a chopper is by no means an inexpensive machine. Although selected minor modifications can be made inexpensively, the choppers which attain show quality, with custom parts and paint jobs, are often valued in excess of $5000. (For comparison, a new 350 cc motorcycle costs less than $1000.)

Mike Bailey founded Custom Cycle, Inc., in November 1970. His product line consists entirely of motorcycle front ends and related components. He began by making glides. (For new terms see Exhibit 1). Now his primary product is a unique springer of his own design.

The handling and stability of a motorcycle are influenced in varying ways by each of the possible modifications found on a chopper. Characteristics which can be linked exclusively to extending the front end are difficult to isolate. To compound the problem, no standard can be established to determine which are the most desirable characteristics.

No attempt will be made here to design an ideal chopper. Examination of three common factors, however, will give insight into this chopper's characteristics. These factors are the length of the wheel base, the effect of tire and spring variations, and the location of the center of gravity.

Extending the front end gives a longer wheel base which, on most vehicles, is associated with a smoother ride. This may not be true on a chopper. Compared to the stock bike, any deflection of the front wheel will cause a smaller angular deflection of the frame and a proportionately smaller deflection of the rider. However, the shock absorber and spring characteristics of a chopper are radically changed when its front end is extended. The chopper, as a result, may adopt

undesirable traits such as a rocking, hobby horse type ride, which are completely different from those of a standard cycle. The change in the angle of castor of the front wheel is also a handicap to low speed maneuverability, but it will have little effect on handling at highway speeds.

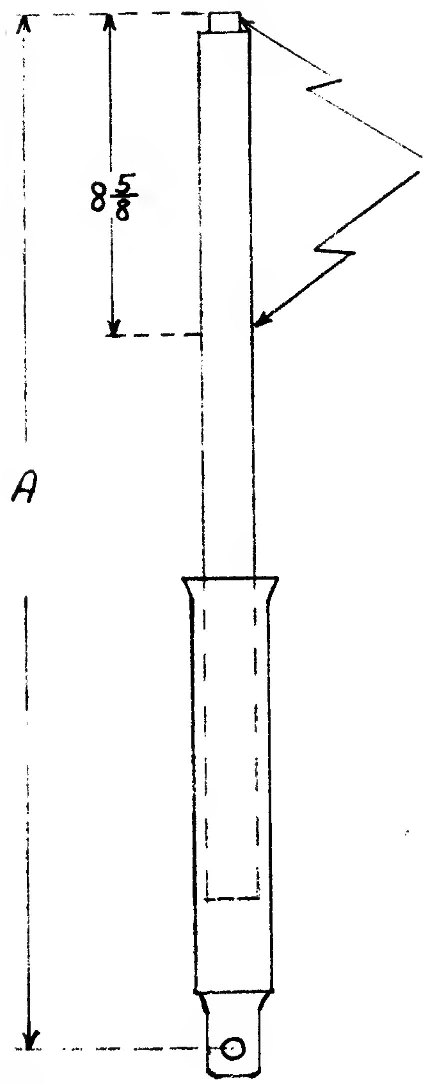
Removal of the rear shock absorber (a common modification on choppers) often leads to the use of a larger, softer tire. The opposite is true in the front. Smaller front tires help decrease the slope of the frame resulting from front end extension. They are also used for purely esthetic reasons. Here, stability and handling will depend entirely on tire type, size, and pressure. Any decrease in the area of contact between the tire and the road will decrease traction.

The third factor deals with the location of the center of gravity and the weight distribution on the two wheels. Any shift in the relative location of the center of gravity will change the weight distribution on the wheels. This weight distribution will depend on the length of the extension, whether the neck is raked or a small front wheel used to lower the slope of the frame, and whether a hard tail is added which lowers the rear of the frame. Other variables include rider weight and position. Stability will be dependent not only on the position of the CG fore and aft which determines the reactions on the wheels, but also the height of the CG which helps determine cornering ability.

From this discussion we can see that predicting the handling and stability for a chopper is only possible on a case by case basis and with much uncertainty. Analysis of the strength of the front forks does not involve such ambiguity. The remainder of this case will be devoted to that pursuit.

The standard front forks on most motorcycles can be classified as glides. Each tube has a spring, internally or externally mounted, and generally has a hydraulic damper which resists compression of the fork. The damper acts to absorb shock but does not inhibit the motion of the spring as it returns the fork to its extended position. If the spring is externally mounted it acts against the bottom bracket of the triple tree, which fastens the tubes to the frame of the cycle. Dimensions of a typical fork are shown on page 3. (Fig. 1)

A springer has three basic parts. (See Figure 2). The support tube attaches to the cycle frame at the triple tree and extends to the rocker which is fastened to it with a pin joint. The rocker acts to transmit forces from the axle to



Triple tree attaches tubes
to frame here

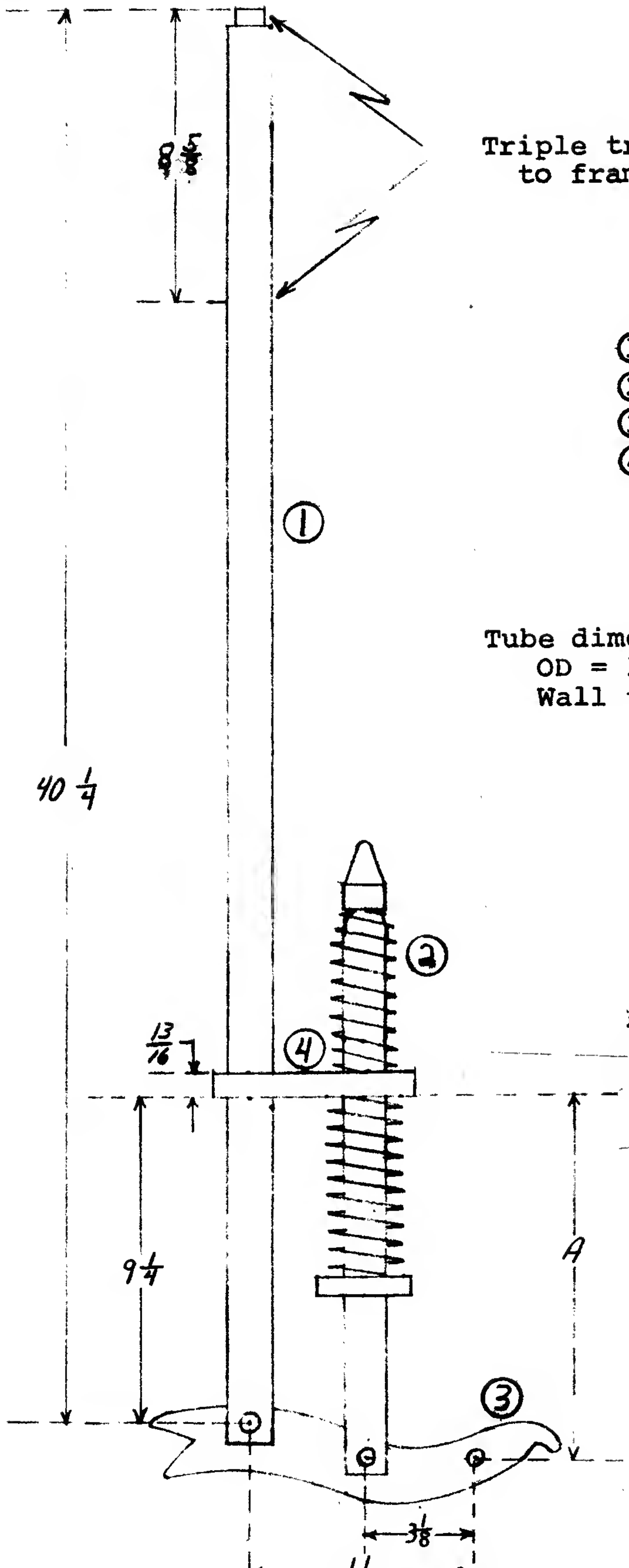
Tube dimensions:
OD = 1-5/16"
Wall thickness = 5/32"

Note: A = 27-1/2" without load.
A = 23-1/2" when spring fully compressed.

STANDARD FRONT FORK TUBE

Figure 1

the support tube and the spring assembly. The spring assembly, attached to the support tube by the tweek bar is also pin jointed at the rocker. The springs may be located near the wheel, (Figure 2) or may be much closer to the triple tree on longer tubes. (Exhibit 1, page 3)



Triple tree attaches tubes
to frame here

① Support tubes
② Spring assembly
③ Rocker
④ Tweek bar

Tube dimensions:
OD = 1-5/16"
Wall thickness = 3/16"

Note:
A = 10-3/8" without load.
A = 8-1/2" with static load of chopper and rider.
A = 6-3/4" when bottom spring is fully compressed

SPRINGER

by Custom Cycle

Figure 2

STUDENT QUESTIONS:

1. For the motorcycle shown in Exhibit 4, use the point of contact of the rear wheel with the ground as the origin of an x-y reference frame (x forward, y upward). The center of gravity of the motorcycle is at x = 25 inches, y = 20 inches. A 200 lb. rider sits so that his center of gravity is x = 13.5 inches, y = 34 inches. What reaction force is exerted on each wheel? The wheel base shown is 52 inches.

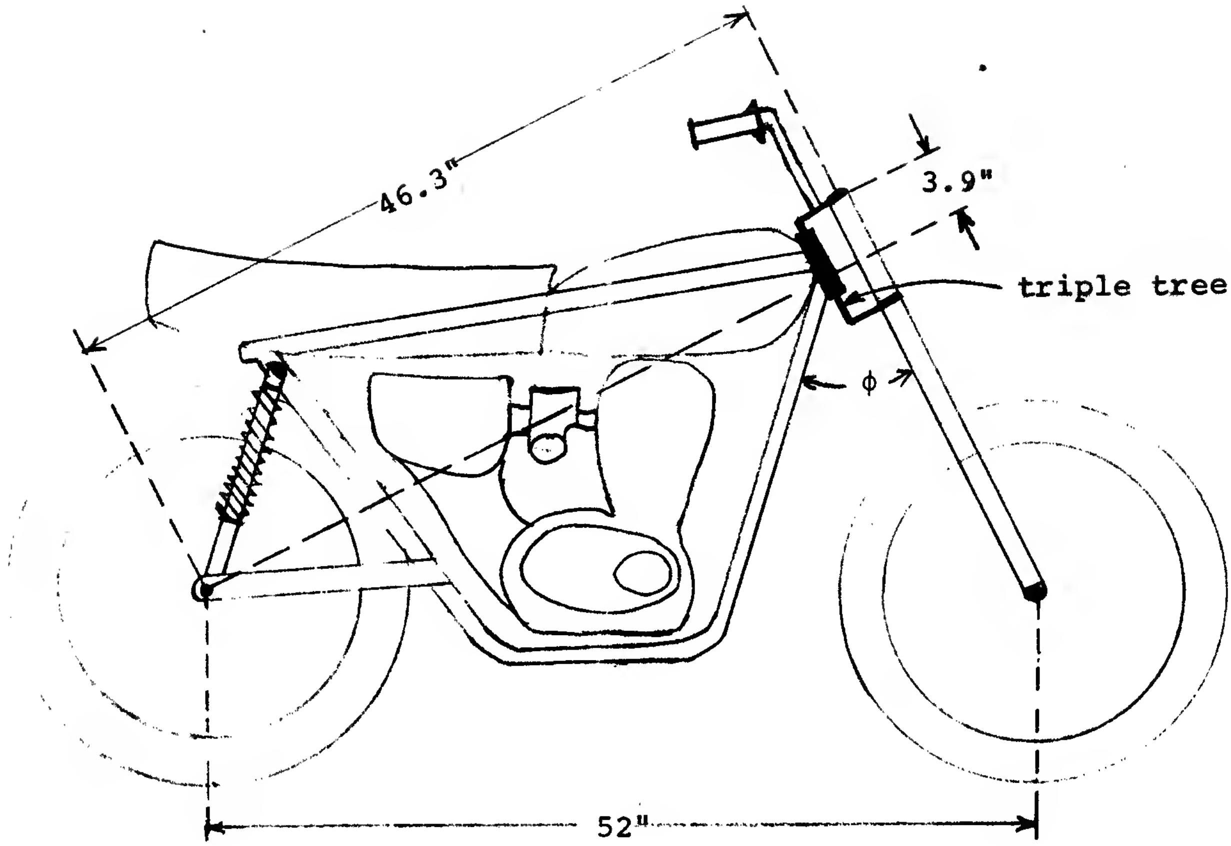
2. Mike's springer mounts to the same triple tree bracket as do the stock forks. Therefore, although the slope of the bike frame and the slope of the support tubes are changed, the angle between the frame and the tubes is the same as on the stock bike. See Fig. 3. When statically loaded with a 200 lb. rider, what is the wheel base for a chopper equipped with Mike's springer? Note that the axle, spring assembly pin, and support tube pin do not fasten to the rocker in a straight line. A graphical solution is recommended.

3. The additional weight of the springer (20 lbs) and the changes in the attitude of the cycle and rider combine in such a way that the x component of the CG remains essentially the same. Taking into account the additional weight of the springer, what reaction force now acts on the front wheel?

4. To find the location of the maximum moment in Mike's springer, sketch the moment diagram of one of the support tubes. Would the maximum moment in the standard forks be located at the same point? Sketch the moment diagram for the standard fork. Use any similarities found in the moment diagrams to explain why slugs are considered unsafe. (See Exhibit 1 for definition of slug.)

5. Too much force applied to the front axle can cause yielding in either the standard tubes or the support tubes of Mike's springer. In each system, yielding will occur only after the springs have been fully compressed. For discussion, assume that both sets of support tubes are made of the same material (though different thickness) which has a yield strength of 55,000 psi. What force, 2P, vertically upward on the axle, will cause yielding at the point of maximum bending moment found in question 4.

6. For a given force, 2P, vertically upward on the axle, what is the bending moment at section A-A of the tweek bar, Fig. 4. (See also Fig. 2)

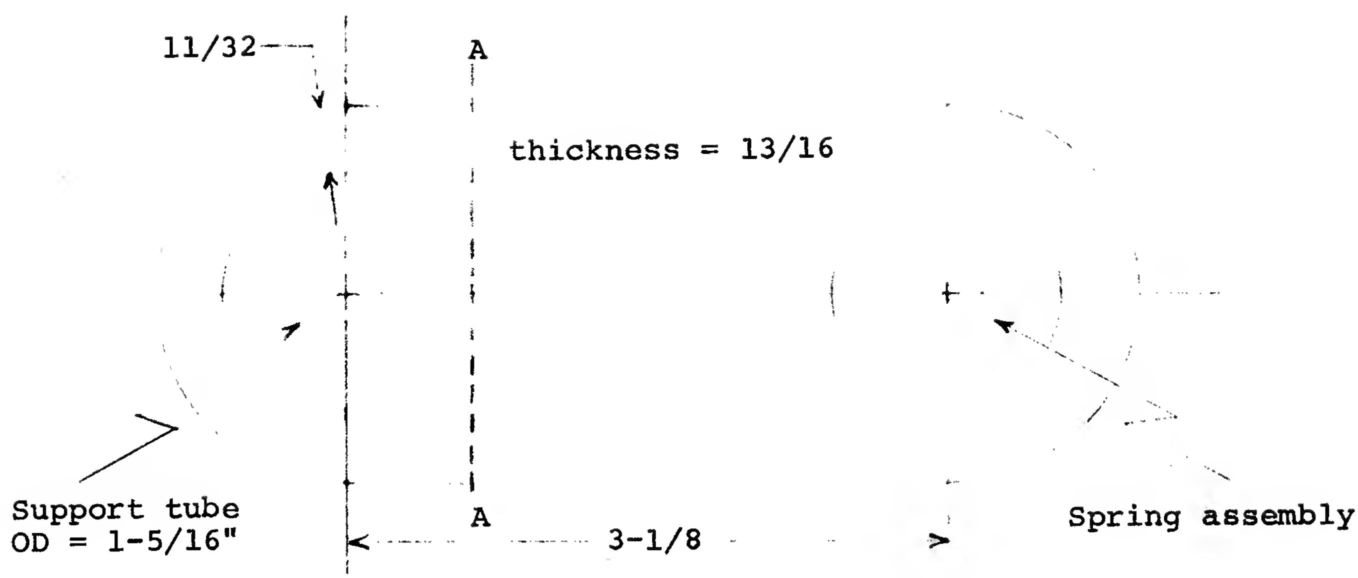


ϕ remains constant

not to scale

Figure 3

TWEEK BAR



NOTE: Method of attachment, tweek bar to support tube, not illustrated

Figure 4

SOME COMMON MODIFICATIONS SEEN ON CHOPPERS

Sissy Bar - slanted backrest to rear of passenger seat which allows passenger to support himself (usually herself) without holding the driver.

Struts - solid metal bar used to replace the rear shock absorber of the stock cycle without changing the slope of the frame. Rear tire is deflated (and sometimes oversized) to cushion the ride.

Hard Tail - metal frame attachment, either bolt-on or welded, which replaces the rear shock absorber assembly, changing the slope of the frame. This lowers the driver's seat. Top frame bar runs in nearly a straight line from the handle bar mounts to the rear axle.

Highway Bar - attached to the frame in front of the engine. This allows the driver to stretch his feet forward for leg comfort on a long ride. With the lower seat from the hard tail, the highway bar gives the driver a reclining appearance. This relaxed sitting position is cited by most owners surveyed as the main advantage of a chopper.

Pull Backs - handle bars which are bent so the grips extend further to the rear. These allow operation of the chopper from the semi-reclining position referred to above.

Front fork extensions:

Slugs - small pieces of tubing (6 to 10 inches), threaded on both ends, which attach to the top of the stock front forks. This is the cheapest, easiest way to extend the front end, but most slugs are considered unsafe.

Glides - appear the same as an elongated automobile shock absorber. This suspension depends on either an internal or external spring and may have a hydraulic piston for damping.

Springer - discussed in text.

Girder - has four tubes like a springer. Identified by the absence of a rocker and its single spring near the handle bars. The girder is a rigid fork (hence the name). As the front wheel is deflected the girder pivots on the bracket which mounts it to the frame. This compresses the central spring absorbing the shock.

EXHIBIT 1

Tweek Bar - a short bracket used either to fasten the spring assembly to the support tubes or as a spacer between the support tubes themselves. See Question 6.

Front ends are usually extended from 6 to 14 inches but any extension over 10 inches normally requires raking the neck of the cycle. Raking increases the angle between the frame and the front forks, lowering the slope of the frame. For a long extension raking and a hard tail are required for the driver to be able to touch the ground.

EXHIBIT 1

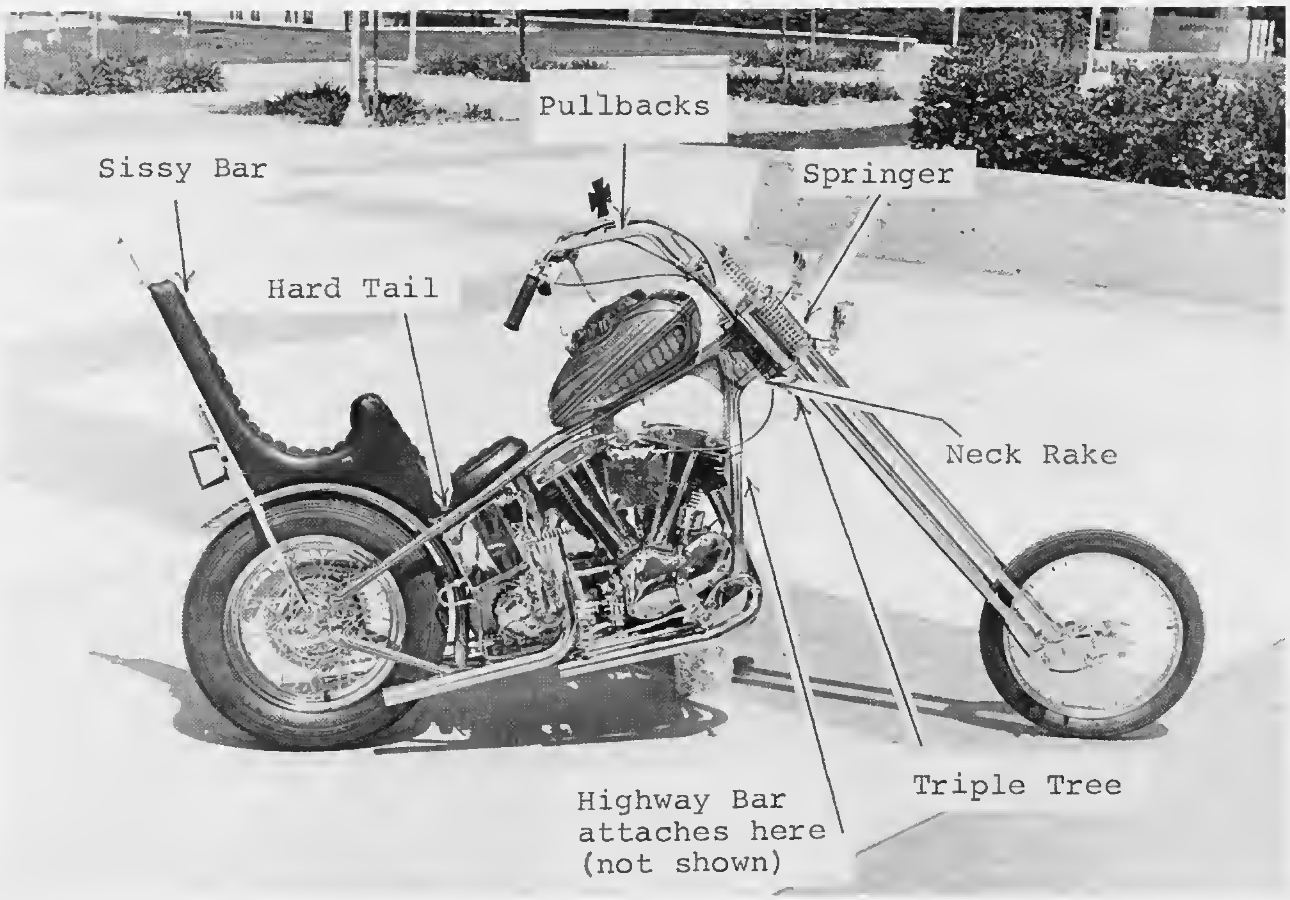
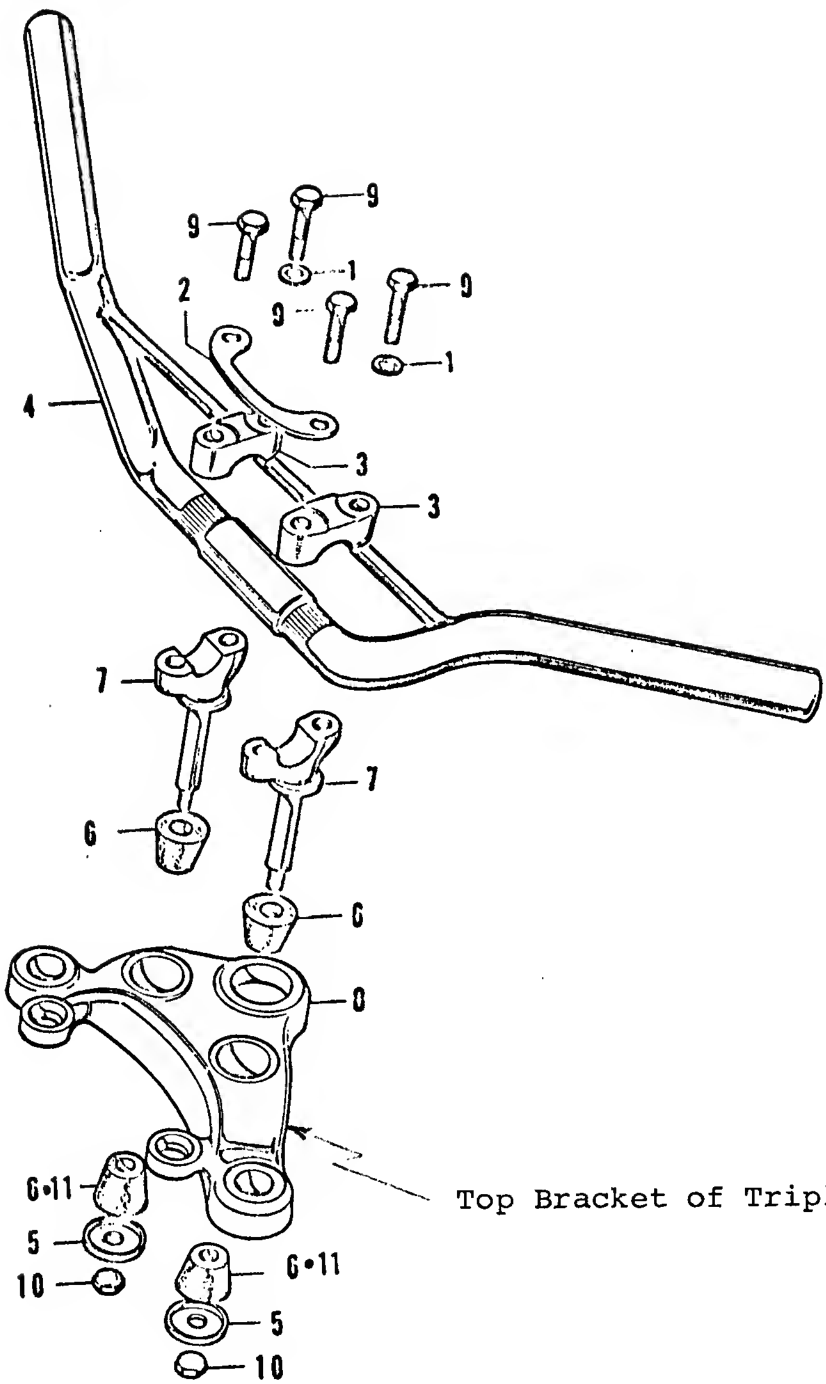


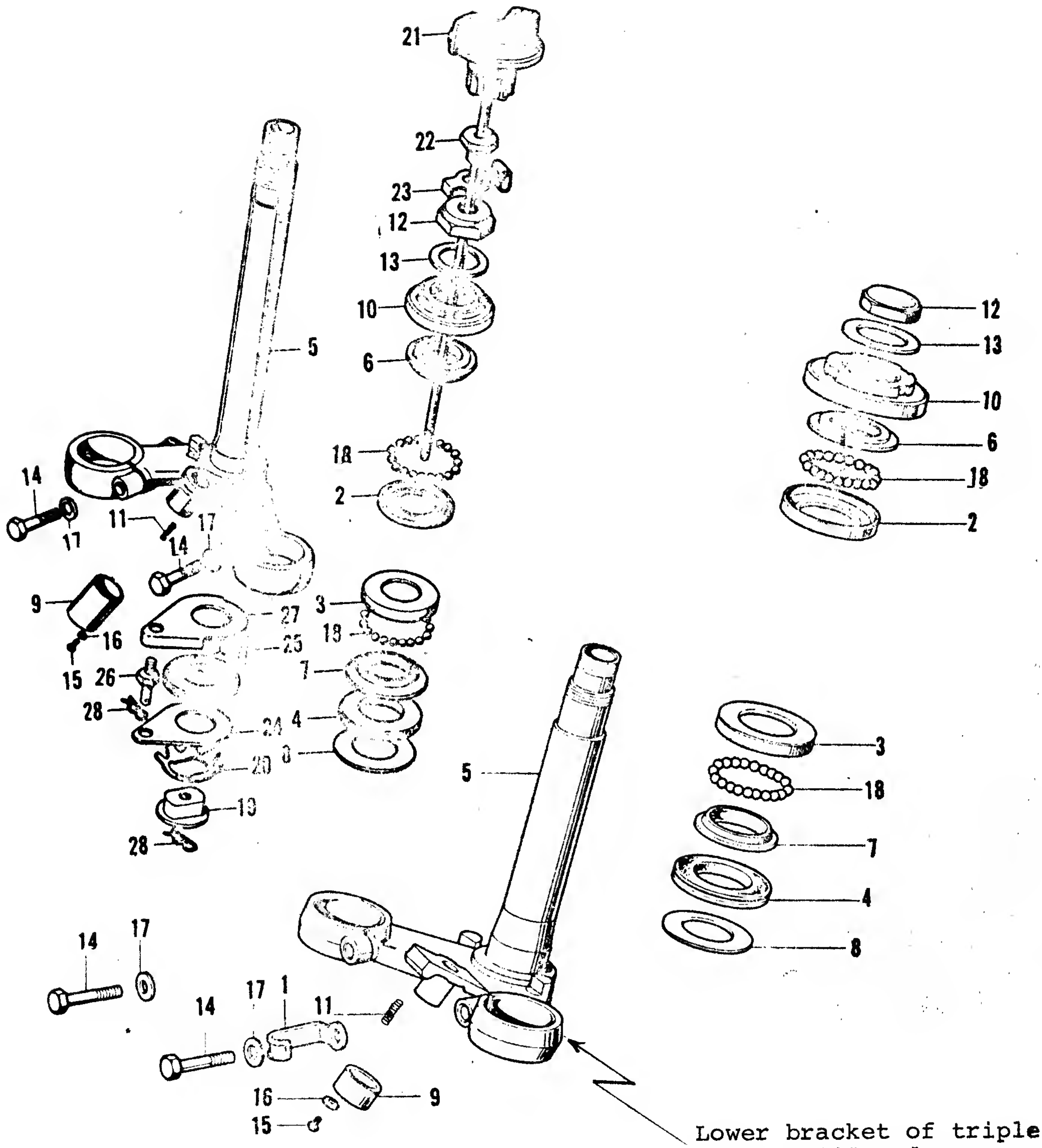
Photo courtesy Street Chopper Magazine
TRM Publications, Inc.

EXHIBIT 1



Top Bracket of Triple Tree

EXHIBIT 2



Lower bracket of triple tree. Slides down over support tubes.

EXHIBIT 2

19 - Fastens to top bracket of triple tree.

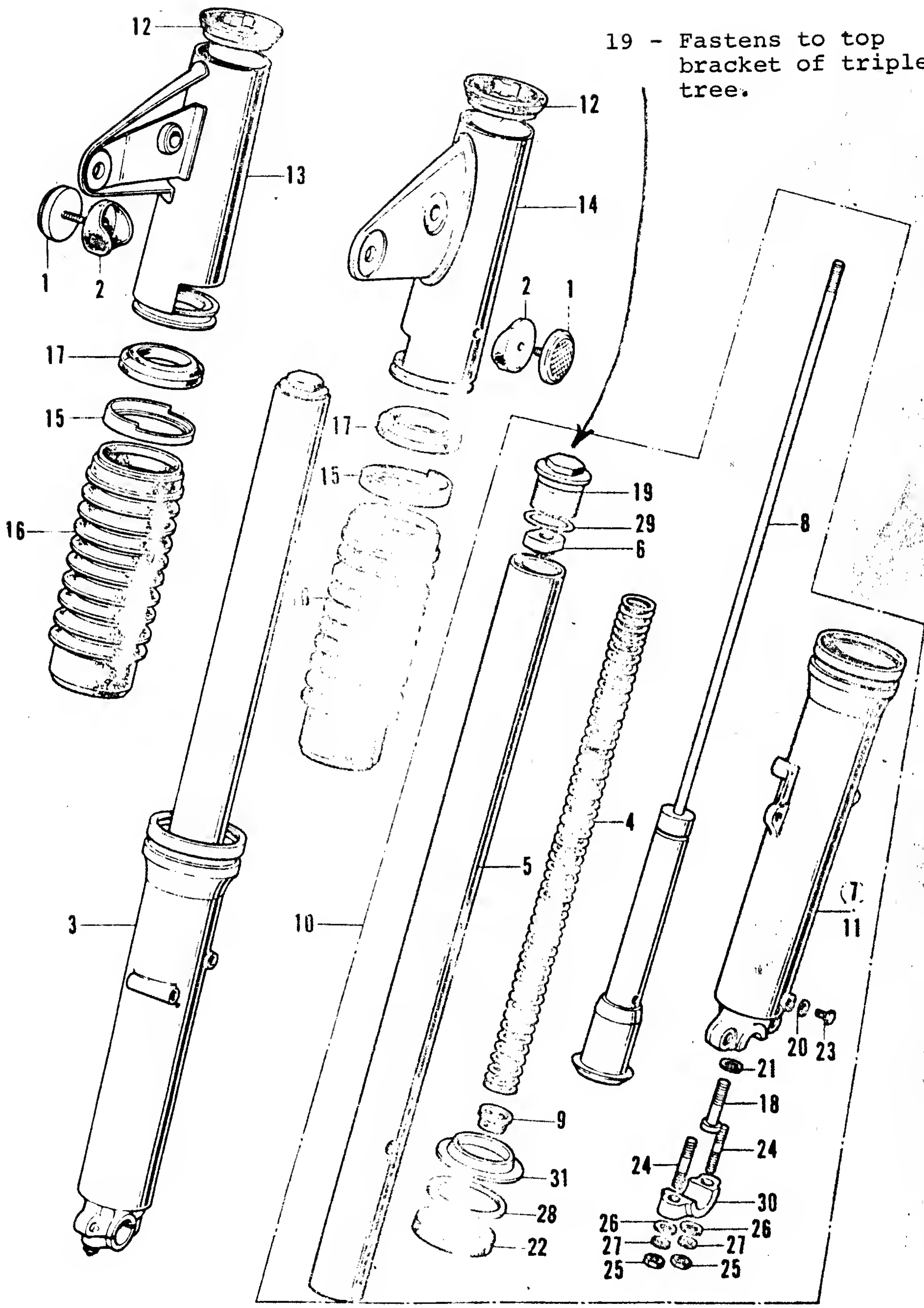
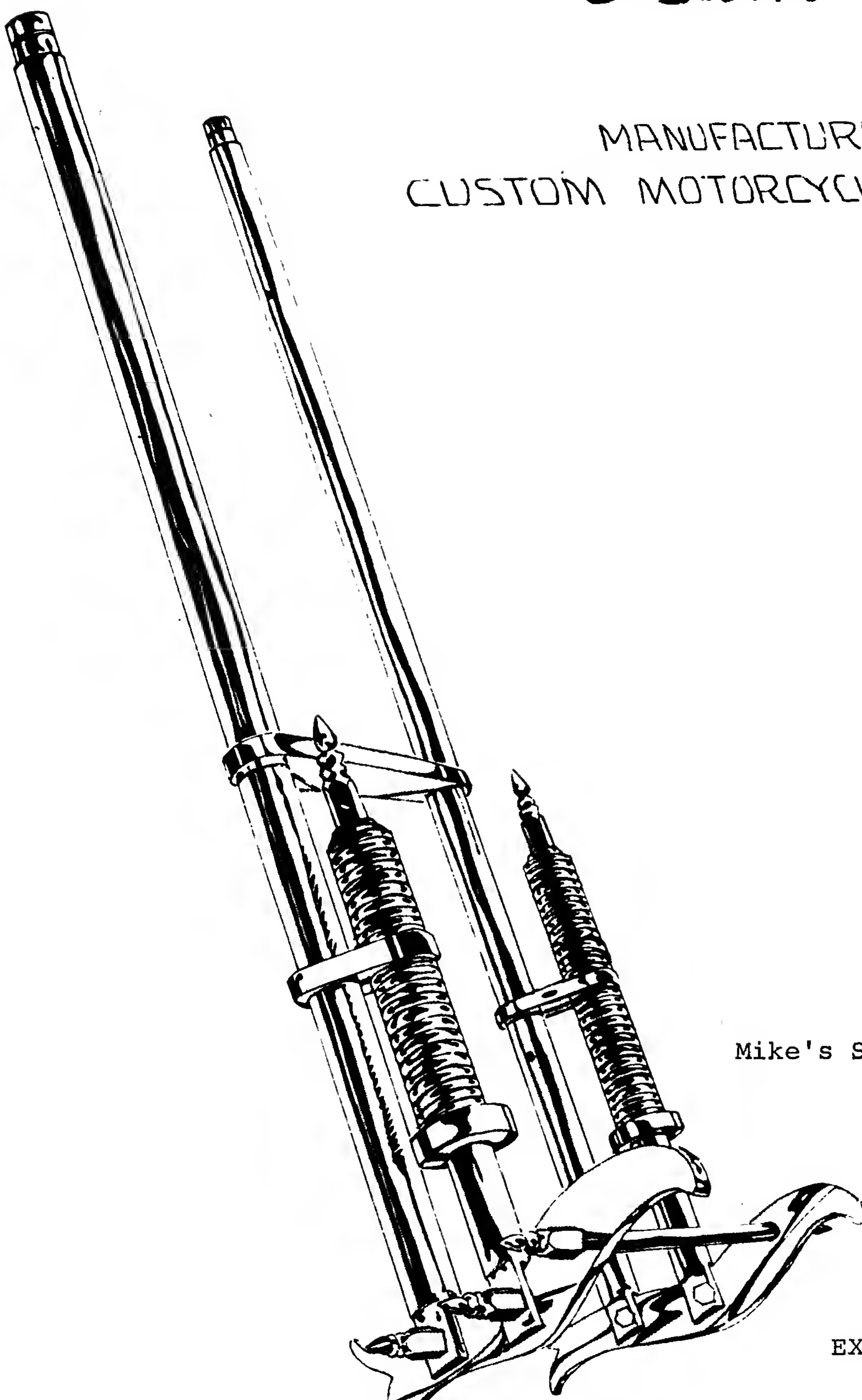


EXHIBIT 2

ECL 203

Custom Cycle

MANUFACTURER OF
CUSTOM MOTORCYCLE ACCESSORIES



Mike's Springer

EXHIBIT 3

SPECIFICATIONS ON THE CL-350 K4

Engine ....325 cc four stroke OHC twin-cylinder

Transmission ....5-speed constant mesh

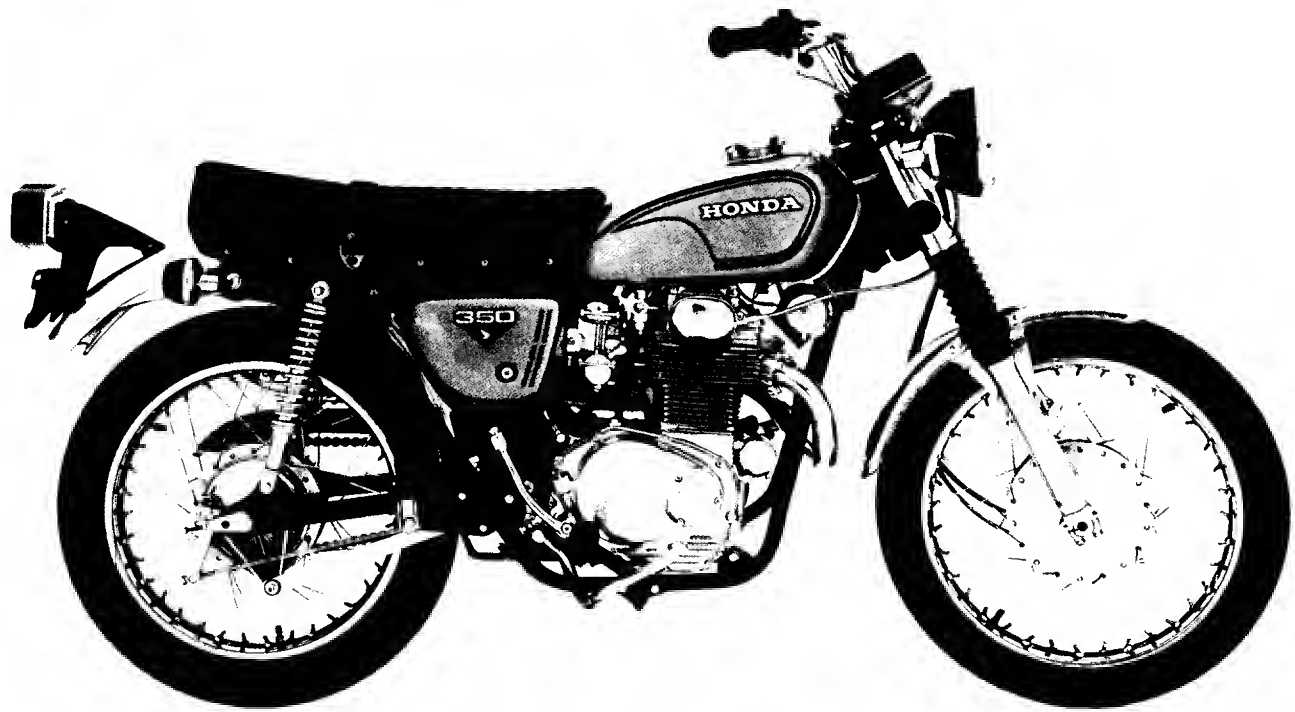
Tire Size
front 3.00-19
rear 3.50-18

Dry Weight ....350 lbs.

Wheelbase ....52.0 in.

Colors ....Dark Red and Candy Gold

All specifications subject to change without notice.



Standard 350 cc Motorcycle
Used as Reference for Calculations

EXHIBIT 4

INSTRUCTOR'S NOTES

1. The reaction force on the front wheel, P, can be found by summing moments about the origin.

$$\Sigma M_O = 0$$

$$= (25 \text{ in})(350 \text{ lb}) + (13.5 \text{ in})(200 \text{ lb}) - (52 \text{ in})(P)$$

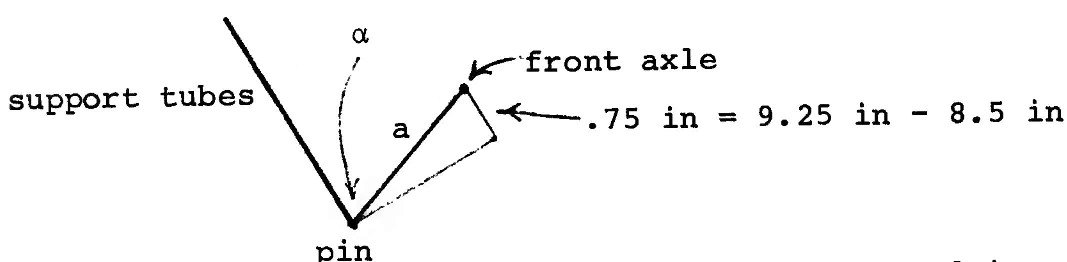
$$\underline{P = 220 \text{ lbs.}}$$

The reaction on the rear wheel is therefore, 330 lbs.

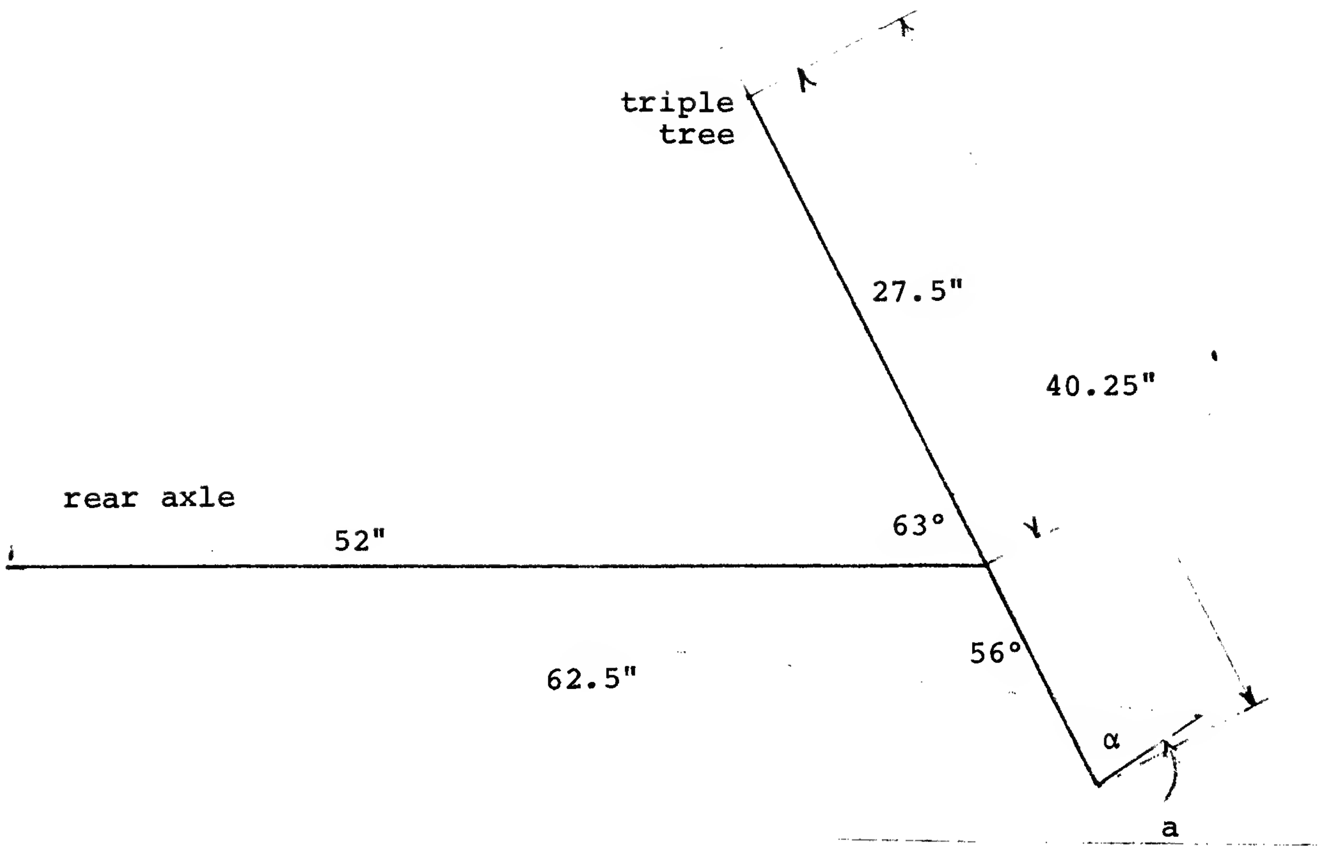
2. Many of the questions asked in this case are most easily answered with a graphical solution. Scale the critical dimensions from Exhibit 4 and Figure 2.

In this question, the rear axle of the bike is the most convenient reference point. Although the front wheel is slightly smaller than the rear wheel, assuming the line between the axles is horizontal introduces an error of less than 1%.

The length of line a between the front axle and the support tube rocker pin is 6.35 inches. With the specified static load, the angle α between the support tubes and line a is 83.2°.



(not to scale)



The wheel base is 62.5 inches. This distance is very sensitive to variation in the angle α. A student who chose α = 90° would get a wheel base of 64 inches.

Note that by "moving the ground" rather than raising the cycle, we have maintained the appropriate angle at the triple tree. The drawing shows that it would be incorrect to assume constant angle of inclination for the support tubes.

Also note that even though the support tubes are 12.75 inches longer than stock, the effect on the chopper is the same as that of an 8 inch glide. The long rocker, therefore, eliminates the need to rake the neck of the bike frame.

3. This is the same calculation as question 1.

$$\Sigma M_O = 0$$

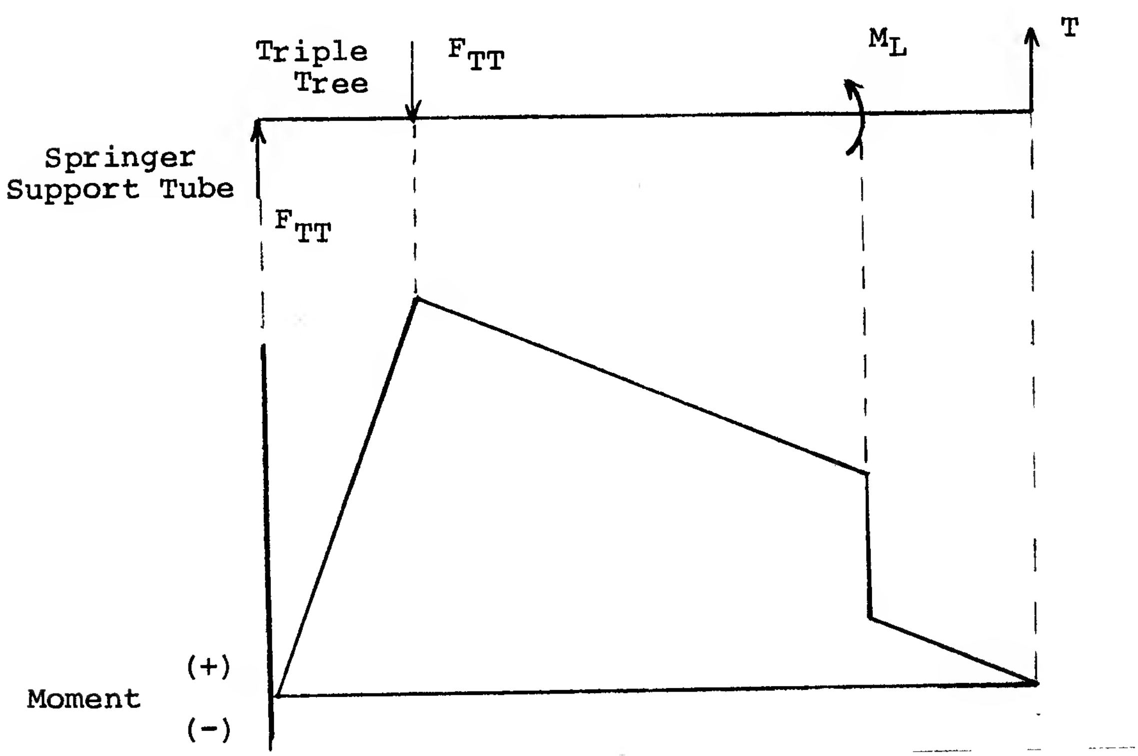
$$= (25 \text{ in})(370 \text{ lb}) + (13.5 \text{ in})(200 \text{ lb}) - (62.5 \text{ in})(P)$$

$$\underline{P = 191 \text{ lbs.}}$$

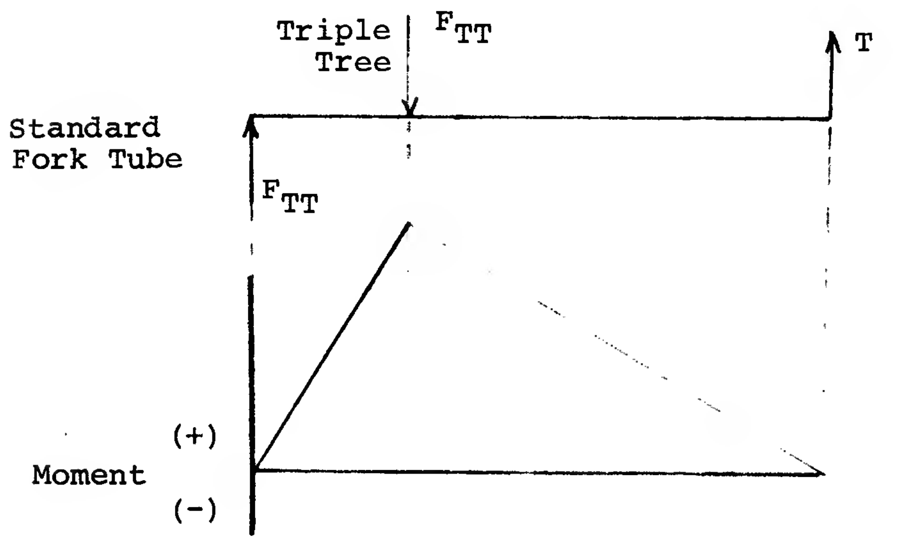
The instructor may wish to have more advanced students check the validity of the assumption that the x component of the CG remains the same. On the drawing of question 2, the combined CG for the stock bike and rider, $\bar{x}$ = 20.8 inches, can be projected onto the new wheel base line. Students would then have to estimate a moment arm for the additional 20 lb load and repeat a calculation similar to the one above.

4. It is very helpful for students to learn to apply this type of mental exercise before attempting to solve a problem. In addition to guiding them to a solution, this approach will help them recognize obvious numerical errors should they occur. These rough sketches (not to scale) provide an outline for answering the questions which follow.

On Mike's springer, the vertical force, P, is resolved into a transverse component, T, perpendicular to the support tubes, and a longitudinal component, L, parallel to them. The longitudinal component will appear in the moment diagram as a bending moment M_L at the tweek bar (bar attaching the spring assembly to the support tubes).



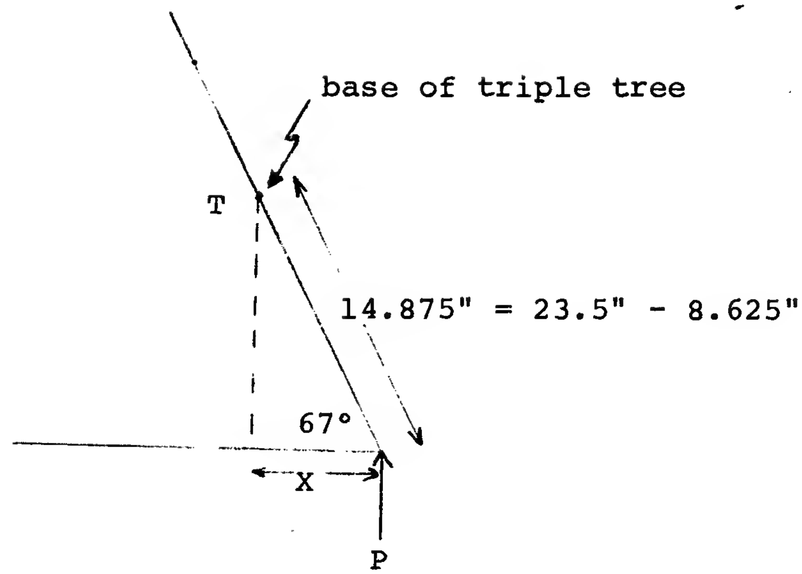
The maximum moment occurs at the lower edge of the bottom bracket of the triple tree. This location will be the same in the stock tubes. Note that the longitudinal force has no effect on the moment diagram for a glide.



The threaded junction between the standard fork tube and a slug, 6 to 10 inches long, would obviously fall near the apex of the triangle of the moment diagram, putting the maximum moment on the weakest part of the extended fork.

5. Question 5 deals with strength of materials, and only the more advanced students should attempt the solution. Instructors may wish to modify the question by giving the section modulae and bending formula, or by specifying an axle force and asking for the maximum moment produced without regard to yielding.

In each system, the angle of inclination of the tubes changes as the springs are compressed. For the standard tube, a 4 inch decrease in length will increase this angle from 63° to 67°. (Modify drawing in question 2.) The applicable moment arm and the maximum allowable axle force, 2P, can then be found.



$$x = 14.875 \cos 67°$$
$$= \underline{5.8 \text{ inches}}$$

Then $M_T = 5.8\ P$

$M_{max} = \frac{\sigma I}{C}$ where $\sigma = \text{Y.S.} = 55{,}000$ psi

$$I = \frac{\pi}{64}\ (1.3125^4 - 1^4)$$
$$= .0966 \text{ in}^4$$
$$c = .65625 \text{ in}$$

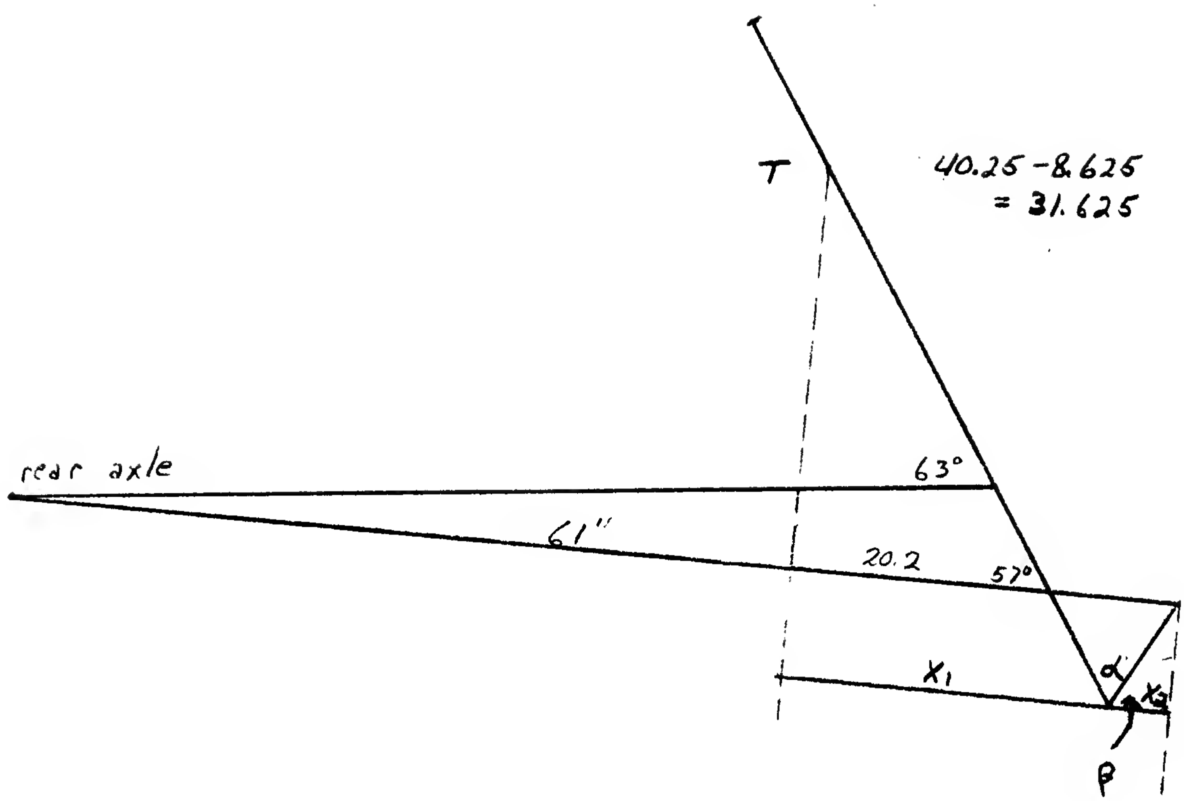
$$M_{max} = 8100 \text{ in/lb}$$
$$P = 1395 \text{ lb}$$
$$2P = \underline{2790 \text{ lb}}$$

When this vertical force, 2P, is applied to the axle, yielding will begin in the support tubes.

For Mike's springer, again a graphic solution is helpful. The rocker length is 6.35 inches (Question 2). When the springs are fully compressed, the angle, α, between the support tube and the rocker is

$$\alpha = \cos^{-1}\left(\frac{9.25 - 6.75}{6.35}\right)$$
$$= 66.8°$$

The axle line can now be drawn.



Note the decrease in the wheel base to 61 inches and the increase in the angle of inclination of the support tubes to 57°.

Although examination of the spring assembly was required to find α, we can now treat the entire springer as a rigid body to find the moment arm, x, and the maximum allowable force, 2P.

$$x = x_1 + x_2$$

$$= 31.625 \cos 57° + 6.35 \cos \beta$$

$$\text{where } \beta = 180° - 57° - \alpha$$

$$= \underline{20.73 \text{ inches}}$$

Then $M_T = 20.73P$

$$M_{max} = \frac{\sigma I}{c} \quad \text{where} \quad \sigma = \text{Y.S.} = 55{,}000 \text{ psi}$$

$$I = \frac{\pi}{64}(1.3125^4 - .9375^4)$$

$$= .108 \text{ in}^4$$

$$C = .65625 \text{ in}$$

$$M_{max} = 9060$$

$$P = 438 \text{ lb}$$

$$2P = \underline{876 \text{ lb}}$$

This is a significant reduction from the stock tubes. Mike's springer is not, in fact, built of the same material as the standard tubes which were analyzed. Equal yield strengths were used to facilitate comparison of the two systems.

Mike claims that the material he uses in his support tubes has a yield strength 30% higher than the figure given. At the same time, it is very likely that the yield strength of the standard tubes is 25% to 30% less than the figure given. These changes would dramatically reduce the apparent discrepancy in the allowable loads. Also, exact specifications were not available for either system, which adds some uncertainty to the dimensions given.

In addition, characteristics of the springer decrease the strength requirements of its support tubes. A chopper is purely a highway bike with no offroad use expected or designed for. The standard cycle, however, must be built to withstand the rigors of off-road handling even though it may be advertised as a street bike.

The required design strength of the front end is also influenced by the longer wheel base. The mass moment of inertia of the chopper is essentially the same as that for the stock bike. A force applied to the front wheel of the chopper, however, has a much longer moment arm on which it can work. The result is a more rapid vertical acceleration of the wheel and less stress in the tubes.

6. For this question the student must trace the applied force through the spring assembly. The lever action of the rocker must also be considered.

When the springs are bottomed, the angle of inclination of the support tubes is 57° (from question 5). The longitudinal component, L, of the vertical force, P, is

$$L = P\cos(90° - 57°)$$

$$= .839P$$

This is the only component of P which causes a moment in the tweek bar.

Considering the lever action of the rocker gives the force in spring, $S = 2L = 1.678P$.

This gives a moment at section A-A.

$$M_A = S(3.125 - .656)$$

$$= 2.469\ S$$

$$= \underline{4.14P}$$

Note: The maximum moment in the tweek bar does occur at section A-A. The instructor may wish to have the students examine whether the tweek bar will yield before the support tube. The tweek bar is made of aluminum alloy with a yield strength of 40,000 psi.